BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Constraints on the Apollo Earth Orbital Timeline Case 310

DATE: November 7, 1967

FROM: R. E. Driscoll

ABSTRACT

This memorandum enumerates and integrates the constraints on the timeline for the earth orbital portion of the lunar landing mission. There are two launch vehicle hardware constraints that bound the allowable stay time in orbit between a minimum of 80 minutes and a maximum of 270 minutes. The crew timeline for earth orbital checkout prior to translunar injection is still in the formative stage of development. A preliminary crew timeline indicates that the minimum time required for space vehicle checkout is about 136 minutes. However, the checkout requirements and the times required for specific system checks are "soft". Finally, the possible effect of two major open items are discussed. These items are: 1) whether air or oxygen is used on the pad to pressurize the spacecraft; and 2) whether or not the spacecraft's inertial platform requires realignment in earth orbit.

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MEMORANDUM FOR FILE

I. INTRODUCTION

This memorandum enumerates and integrates the constraints on the timeline for the earth orbital portion of the lunar landing mission. At this point in time there are relatively few hard constraints. There are two constraints dealing with the S-IVB and Saturn V Instrument Unit (IU)* which bound the allowable stay time in orbit prior to Translunar Injection (TLI) and are discussed in Section II. The crew tasks and timeline from insertion to injection are preliminary in nature pending flight and simulation verification. This applies not only to the estimate of the time required to perform the systems checks but to the necessary system checks as well. Section III presents a preliminary timeline and discusses the operational and systems constraints involved in effecting the checkout.

There are two major open items which can impact the minimum time required to prepare the spacecraft for TLI. The first is the type of atmosphere used to pressurize the CM on the pad and the second deals with the need to realign the spacecraft's inertial platform (IMU) prior to TLI. These items are discussed in Section IV.

II. SPACE VEHICLE HARDWARE AND SOFTWARE CONSTRAINTS

There are two constraints dealing with the S-IVB that initially bound the minimum and maximum stay time in earth orbit prior to Translunar Injection (TLI). First, the S-IVB requires 80 minutes before a restart is possible in order to allow the J-2 engine turbine system to cool sufficiently for a stable restart. This constraint, therefore, defines the minimum time that must be spent in earth orbit. (The constraint essentially negates the possibility of TLI occurring during the first Atlantic and the first Pacific opportunities). Secondly, the IU has been designed to ensure a lifetime of 6-1/2 hours. As a result, the IU systems were designed with safety margins sufficient to meet this requirement with a high degree of confidence. With these margins,

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*A directory of abbreviations is contained in Table II.

the systems limiting the IU lifetime are the electrical power system and the environmental control system. Upcoming Apollo test missions will provide additional systems data and could result in an increase of IU lifetime without significantly affecting the reliability of the IU systems. Since two hours have been allocated to post TLI operations (transposition, docking, and separation), a maximum of 4-1/2 hours or 270 minutes remain for earth orbital operations. Four and one-half hours then define the current maximum stay time in orbit prior to TLI.

There is one launch vehicle performance and software constraint. This constraint limits the number of alternate injection opportunities to one and requires that the one alternate opportunity occur during the orbit preceding or following the prime injection opportunity. This does not further limit injection opportunities, in light of the two previously mentioned hardware constraints, rather it indicates that the two possible injection opportunities are currently in the second and third orbits.

The only other identifiable launch vehicle constraint prohibits the maximum commanded attitude in the yaw plane from exceeding 45°. This constraint is imposed to prevent gimbal lock on the ST-124 (IU inertial platform). This constraint should have no effect on the timeline even if the spacecraft's IMU is realigned in earth orbit.

There are no known spacecraft hardware constraints which affect the earth orbital timeline. The spacecraft does have an attitude constraint similar to that mentioned for the S-IVB/IU. That is, the maximum commanded attitude in the yaw plane must not exceed 70°. Again, this has no effect on the timeline.

III. OPERATIONAL CONSTRAINTS AND CHECKOUT REQUIREMENTS

Communications and Tracking

There are two operational constraints dealing with the communication requirements in earth orbit prior to TLI (Reference 10). The first states that a minimum of two tracking, command, telemetry and voice contacts of four minutes minimum duration above 5° elevation is required prior to injection. If injection does not occur in the first revolution two such contacts are required per revolution. The second requirement states that at least one four-minute contact above 5° elevation with a ground station having command, telemetry, and voice capability is required during the one-hour period beginning ninety minutes before and ending thirty minutes before translunar injection ignition. These constraints represent the minimum communications required for: 1) orbit determination; 2) GO/NOGO decisions and time hacks; 3) determining physical condition of the crew; 4) ground assessment of space vehicle systems and consumables; and 5) ground generated update of state vector and TLI parameters. With the presently planned MSFN stations and with optimum placement of communication ships, these constraints do not appear to affect any injection opportunities, commencing with the second orbit which is considered to present the first opportunity due to the S-IVB constraint mentioned in Section II. (Reference 12 and 13 verify adequate communications coverage.)

Checkout

The next item to be discussed is the checkout activities and requirements prior to TLI. This is one of the most important areas in terms of constraining the orbital timeline and also happens to be one of the "softest", at this time. The reason is the lack of in-flight and simulation data needed to verify the times and checkout procedures required prior to the TLI decision.

Table I contains a representative earth orbit timeline and sequence of events. It was extracted from Reference 1 but was modified to reflect an oxygen atmosphere, rather than air, in the CM at liftoff. Included in the table are: 1) the individual crew member activities in earth orbit; 2) time referenced to liftoff; 3) ground communication coverage above 5° elevation, and 4) intervals during which the space vehicle is in earth shadow. Also shown as a function of time from liftoff are the injection opportunities.* Appendix A contains a brief description of each activity performed in earth orbit.

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*Inherent in the Apollo earth-moon geometry is the existence of two discrete launch windows each day. Launches from these windows generally result in two markedly different translunar trajectories. One significant identifying characteristic is that the translunar injection points associated with one window tend to fall in the vicinity of the Atlantic Ocean and TLI points for the other window fall in the Pacific vicinity. Hence, these launch windows have come to be distinguished as Atlantic opportunities and Pacific opportunities. For each launch window, a TLI opportunity will occur once each orbit; thus, we have a first (orbit) Atlantic opportunity, first Pacific opportunity, second Atlantic opportunity, etc. The exact time of any TLI depends on the declination of the moon. Table I shows the time "bracket" for each opportunity where a bracket encompasses an entire lunar month or cycle (from ascending node to ascending node).

The operations enumerated in Table I can be grouped into three general functions: 1) post insertion evaluation; 2) systems capability evaluation; and 3) the final preparations for the injection maneuver. The post insertion evaluation is performed in about the first ten minutes following the first S-IVB cutoff. It consists of a preliminary evaluation of the critical space vehicle's systems status, after being subjected to the launch environment, and a determination of the safety of the earth parking orbit. The system status is assessed jointly by the crew, using on-board displays, and by ground support personnel using space vehicle telemetry data. The determination of the achieved orbit is primarily done on the ground using radar tracking data and outputs from the launch vehicle and spacecraft on-board navigation systems. In addition, the crew must reconfigure the spacecraft for coasting flight. (During the launch phase, the spacecraft is configured for a possible abort; hence, it has equipment operating in modes not required in earth orbit. For example, the SPS gimbal motors are activated during the launch phase. This requires the EPS to be configured for peak power loads. After insertion into a safe earth orbit, the gimbal motors are turned off and the EPS configured for coasting flight in order to conserve electrical power.)

The second function (the systems capability evaluation) requires the majority of time in earth orbit, extending from about insertion plus ten minutes to about injection minus eleven minutes or a total duration of approximately 115 minutes. It is during this interval that detailed systems checkouts are conducted including dynamic checks on all components and alternate modes necessary for crew safety. Many of the operations do not provide maintenance or improve the status of the system in the sense that a restoration of consumables or an inertial platform alignment improve that status. Instead, these operations are directed toward verification of the system status following launch into earth orbit. For instance, the fuel cell purge activity demonstrates the condition of the purge system; it does not markedly improve the status of the fuel cells. (Purges normally are scheduled at 24-hour intervals.) Even the IMU realignment may be justifiable solely as verifying the condition of the optical alignment equipment. However, all these system checks are time consuming, impose a heavy work load on the crew, and can impose additional constraints on the required time in orbit. These constraints will be discussed shortly.

The last function to be performed in earth orbit is the final preparations for the TLI maneuver. This consists of a final systems status check and a reconfiguration of the spacecraft's systems for the injection maneuver and requires about

10 to 15 minutes (11 minutes in Table I). The spacecraft reconfiguration consists mainly of insuring that: 1) the necessary C&N monitoring program is called up and properly updated; 2) the SPS is properly conditioned in the event it is required for an abort; 3) the electrical power system is prepared for peak power load operation; and 4) the Caution and Warning System indicates no system malfunctions. The crew also monitors the TLI attitude maneuver, the S-IVB ullage engine ignition and thrusting, and performs a final countdown to S-IVB engine ignition.

The sequence of operations as depicted in Table I is constrained by the following factors: 1) activities that must be performed during a particular time interval; 2) activities that require more than one crew member; and 3) activities that must be performed serially. The heavy arrows on Table I indicate items within the earth parking orbit operations which are constraints in that they are serial, require more than one man, or are dependent on communications, lighting, etc.; the lighting and communications constraints however will be very sensitive to the launch date and time. The systems capability evaluation (or detailed systems checks) is constrained by all three factors and since this function constitutes the major constraint on the total length of the timeline, the following discussion will be restricted to activities performed within this time interval.

Systems Capability Evaluation

The key constraining item in Table I is the IMU alignment. The reason it is the key is that it was assumed that the alignment must be performed with the space vehicle in earth shadow. This assumption is based on previous manned mission experiences during which the astronauts have had difficulty acquiring stars while in daylight in near earth orbits. This inability to locate stars is thought to be caused by earth shine while in low altitude earth orbits and by sunlight reflected off the spacecraft's structure into the optical field of view. Additional attempts will be made on Apollo test missions but until it is proven that stars can be seen in earth daylight, IMU alignment will be planned to occur in earth shadow. This obviously complicates the construction of the earth orbital portion of the lunar landing mission timeline. Since launch time is dependent on launch date and the date of the lunar landing mission is not now known, there is no way of predicting how early or late after insertion into earth orbit the space vehicle will enter earth shadow. It is quite possible that during the beginning of a launch window there is sufficient time to perform an IMU alignment early in the first orbit, but at the end of the launch window there is not sufficient time and hence, the alignment must be postponed until the next orbit, possibly resulting in a missed injection opportunity. However, let us assume, as was done in Table I, that the launch date and time are known and the alignment is scheduled to occur in earth shadow. The IMU alignment requires the use of the Command Module Computer (CMC). Operations which require the use of the CMC are performed serially. Thus other activities such as the pulsed integrating pendulous accelerometer (PIPA) bias check, state vector update and Guidance and Navigation System ΔV preparations, must be scheduled around the alignment. A delay in completing any of these activities will serially add to the total checkout time. In addition, the alignment requires the space vehicle to be oriented in a stable attitude; hence, dynamic checks, such as the SM RCS firing test, that disturb the orientation must be conducted before or after the alignment.

There are other operations besides the IMU alignment that constrain the timeline in that they must be performed at a fixed time. These are activities that require spacecraft/ground communications such as the communications test, the state vector and thrusting parameter updates, ground participation in ECS post check and GO/NOGO decisions. Failure to perform these tasks within the limited ground station contact times will impact the time in orbit. (Because of the total length of the timeline in Table I, this does not appear to be a problem. However, it could be a problem if TLI occurred at the beginning of the second Atlantic opportunity.)

Other possible constraining activities involve the ECS redundant component check and the ECS post check. (The ECS post check is essentially a continuation of the redundant component check.) These tests are conducted to detect any inoperative or malfunctioning components that might be selected for use later in the mission. However, several redundant components are not checked because: 1) an excessive amount of oxygen would be required; 2) a means of selection is not incorporated; or 3) a direct indication is not available. In addition, some parameters are only telemetered to the ground and the information relayed back to the crew. Both tests require two or three men and some portions of the tests require that one man be located in the lower equipment bay (LEB). These tests obviously require close coordination and timing.

In summary then, few of the spacecraft systems checkout items are themselves constraining elements in the sense that the S-IVB minimum restart time is a constraint. Some constraints ensue from serial operations, etc., but the real constraint results from the total time required to perform all of the desired checkout operations. Some of the checks could be eliminated with no increase in the probability of catastrophic failure (e.g., the EPS battery charger need not be verified prior to TLI; enough power remains to permit an abort after TLI even if the charger is inoperative). All of the systems are checked and monitored prior to liftoff so that the earth orbital checkout becomes one of determining degradation from the Saturn V Launch environment. The checkout operations are not performed for purposes of determining required repairs; rather they are designed to detect abort circumstances prior to the TLI commitment.

Regarding the "total time constraint" this preliminary estimate (Table I) of activities required prior to TLI shows that about 136 minutes are required in earth orbit. Assuming for the moment that this estimate is firm, there would be no second Atlantic injection opportunity regardless of flight azimuth or launch date. (The first Atlantic and first Pacific opportunities were eliminated by the S-IVB restart constraint.)

On the other hand, Reference 11 shows that the required time in orbit prior to TLI is about 84 minutes, which would allow a second Atlantic opportunity on essentially any launch day. Both timelines have basically the same system checkouts; however, they differ significantly in the estimated times to complete the activities and in the detailed items checked. Until the times required for given activities become "real" rather than "estimates" and the specific system checks become mandatory rather than highly desirable, the impact on the earth orbital timeline cannot be fully assessed. Test missions and simulations prior to the lunar landing mission will provide this information.

IV. OPEN ITEMS WHICH COULD IMPACT THE TIMELINE

There are two items, currently under investigation, which could impact the earth orbital timeline. The first concerns the use of an air or pure oxygen atmosphere to pressurize the CM on the pad. If air is selected, the CM atmosphere may require enrichment with oxygen prior to TLI. (Oxygen enrichment will, of course, be required to achieve a viable CM environment). There are basically five interrelated parameters that are being considered in the studies to generate an acceptable procedure for enriching the air. They are: 1) the allowable time interval by which the CM atmosphere must be made viable; 2) the required percentage of oxygen in the atmosphere prior to TLI; 3) the quantity of gaseous oxygen allowed for enrichment; 4) the various combinations of gaseous and cryogenic oxygen flow rates; and 5) the allowable level of depressurization.

As an example of the possible impact on the earth orbital timeline, a preliminary analysis of the sequence of operations indicated that oxygen replenishment of an air atmosphere added 18 minutes on to an already lengthy 136 minute minimum time prior to TLI (Reference 1). The procedure for oxygen replenishment in Reference 1 requires all three crew members. Each crew member must: 1) verify suit integrity, spacecraft connections and switch positions prior to cabin dump; 2) conduct suit leak checks during the dump; and 3)monitor pressure build-up. Several words of caution are appropriate. Neither the above mentioned minimum timeline nor the oxygen replenishment procedure has been verified in-flight or by simulations. Also, there are several other procedures for oxygen replenishment that require less or more time than the 18 minutes mentioned above. (References 2 through 7 provide additional information on this subject.)

The second open item concerns the need for a spacecraft inertial platform (IMU) realignment prior to TLI. The spacecraft guidance system is a backup to the launch vehicle guidance system for this maneuver. Hence, a realignment enhances the accuracy of the maneuver if it is performed in the backup mode. The IMU is initially aligned prior to liftoff. The azimuth alignment is verified by sighting on a ground target with the spacecraft's optics before spacecraft close-out (about T-10 hours). The azimuth alignment is maintained by gyrocompassing until the platform is released (inertially fixed) shortly before liftoff. However, due to the inaccuracy of gyrocompassing, the azimuth uncertainty increases during this period of time. After liftoff, platform drift further increases the inaccuracy of the inertial reference. A study has been performed (References 8 and 9) to compare, in terms of the 3σ penalty at the first midcourse correction (MCC), the earth orbital and translunar injection navigation capabilities of the launch vehicle and the spacecraft and to compare the advantages of spacecraft platform realignment versus no realignment. In brief, the advantage of a realignment (a state vector update was assumed for both cases) is only about 16 fps (3σ) in the first MCC. In addition, it may be operationally preferable to realign the platform prior to TLI to establish confidence in the spacecraft's optical alignment system. If realignment is deemed necessary, it would require from 20 to 30 minutes and could constrain other checkout operations.

V. SUMMARY

All identifiable constraints to the earth orbital timeline have been listed and briefly discussed. Due to the S-IVB restart constraint, the space vehicle must remain in orbit at least eighty minutes. This precludes using either the first Atlantic or first Pacific opportunity. Due to the current S-IVB/IU orbital lifetime constraint the maximum time in earth orbit is 270 minutes. These constraints permit second and third injection opportunities from either launch window.

The operational constraints and checkout requirements were presented. The amount of time required for systems checkouts is soft, pending flight and simulation verification, and could further constrain injection opportunities. Finally, two open items have been identified which could affect the orbital timeline; namely, 1) whether air or oxygen is used on the pad, and 2) whether or not an IMU realignment is required in earth orbit.

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Attachments
  Appendix A
  Table I
  Table II
  References

APPENDIX A

The following is a brief description of the activities shown in Table I.

Post Insertion Check - This check consists of: 1)a preliminary evaluation of critical spacecraft systems, such as the ECS and the EPS; 2) a determination of the achieved orbit after which the GO/NOGO decision is made; and 3) reconfiguring the spacecraft for coasting flight. (This includes deactivating the SPS gimbal motors, safing the pyrotechnic devices, disabling the CM RCS propellant jettisoning logic and removing the entry batteries from the main power busses.)

SM and CM RCS Monitor - The SM RCS check includes verification of switch positions, quad temperatures, helium pressure and percentage of propellant quantity remaining. The CM RCS check includes verification of switch positions, a check of helium temperature and pressure, and a pressure check of propellants. The RCS is not fired during these checks.

ECS Monitoring - This check consists of verifying that the following items are within specific limits: 1) ECS radiator inlet and outlet temperatures; 2) glycol evaporator outlet temperature; 3) evaporator steam pressure and discharge pressure; 4) temperature and pressure of suit and cabin; 5) partial pressure of CO_2; 6) oxygen flow rate; and 7) water quantity.

SPS Monitor - This check includes verification that the pressures and temperatures of the propellant tanks are within specific limits and a test of the propellant utilization and gauging subsystem.

EPS Monitoring - This includes: 1) a cryogenic pressure-quantity check; 2) a fuel cell power plant check; 3) a D-C Voltage-Amperage check; and 4) an A-C Voltage check.

ECS Redundant Component Check - This includes: 1) the redundant suit compressor check; 2) the ECS redundant glycol pump check; and 3) the number 1 and number 2 O_2 demand regulators checks.

Docking Check - This consists of activating the docking probe and verifying on displays that it extends fully.

Battery Charging - This consists of connecting the battery charger to an entry battery and verifying battery charging capability.

PIPA Bias Check - This consists of programming the computer to accept accelerometer readings during the coasting flight, for about a five-minute interval, to determine accelerometer bias.

Single and Dual Inverter Operation Check - This check is accomplished by placing the standby inverter or inverters on A-C bus 1 or 2, one at a time and removing the active inverter from the bus to which the standby inverter is applied.

Pyro Battery Check - This check consists of a voltage-amperage check of the two pyro batteries.

SPS Line Heaters - This check is accomplished by activating the SPS line heaters, using the two alternate modes available, and monitoring the SPS propellant tank temperature for 10 minutes, for each mode selected, to detect an increase in temperature to insure proper heater operation.

Manual Cryo Heaters and Fans Test - This is accomplished by activating the heaters and fans using the alternate manual mode and monitoring the cryogenic tanks for a pressure increase.

Entry Monitoring System (EMS) Check - The EMS has five test positions to check the operational status of the system. All five test positions are activated and checked.

IMU Fine Alignment - This consists of 1) programming the computer for alignment; 2) selecting stars for the alignment; 3) maneuvering the space vehicle for star acquisition; 4) using the optics to sight on and mark the stars; 5) monitoring computer processing; and 6) performing a fine alignment check.

Communications Test - This consists of checking the various communication modes of the unified S-Band system.

Caution and Warning System Verification Check - This check consists of a check of the lamps in the C&W system on the main display console.

SM RCS Thruster Firing Test - This is a dynamic check of the SM RCS thrusters. Thrusters are fired momentarily to provide plus and minus pitch, yaw and roll movements which are monitored by the crew.

SCS Alignment - This consists of aligning the backup attitude reference system to the IMU reference.

Condition Lamp Test - This is a check of the G&N system condition lamps and involves activation and testing of the condition lamps in the lower equipment bay.

Water Gun Test - This consists of actuating the water gun to verify its operation.

Urination - This is a test of the urination subsystem using water for simulated urination.

ECS Post Check - This is essentially a continuation of the ECS redundant component check. It includes: 1) checks of main regulators 1 and 2; 2) checks of all suit circuits using accumulators 1 and 2; 3) checks of redundant urine dump heater (requires ground participation); 4) checks of the glycol secondary coolant loop; and 5) checks of two cabin fans.

Guidance and Navigation System ΔV Preparations - This consists of a ground generated update of the spacecraft's state vector and thrusting parameters, a verification of IMU alignment and a verification of the CMC pre-thrusting program.

Fuel Cell Purge - This is a check of the fuel cell purge subsystem. Purging is accomplished by sequentially purging O_2, then H_2, on each fuel cell, one at a time.

Final TLI Preparations - This check consists of: 1) calling up the CMC thrusting program and verifying that it is properly updated; 2) connecting the entry batteries to the main busses in preparation for peak power load operation, and configuring the EPS for dual inverter operation; 3) setting the proper SPS gimbal angles and activating the SPS gimbal motors; 4) verifying status of the C&W system; 5) monitoring the space vehicle's TLI attitude maneuver; and 6) performing a final countdown to S-IVB engine ignition.

TABLE 1 — PRELIMINARY EARTH ORBITAL TIMELINE (3 P.M. LAUNCH TIME ASSUMED)

INJECTION OPPORTUNITIES*	TIME FROM LIFT OFF (MIN.)	GROUND COMMUNICATION COVERAGE	COMMANDER (C) (LEFT COUCH)	NAVIGATOR (N) (CENTER COUCH)	SYSTEM ENGINEER (SE) (RIGHT COUCH)	EARTH SHADOW
	0	USA	LAUNCH	LAUNCH	LAUNCH	
1st ATLANTIC	10		INSERTION	INSERTION	INSERTION	
			POST INSERTION CHECK	POST INSERTION CHECK	POST INSERTION CHECK	
	20		SM & CM RCS MONITOR	ECS MONITORING	SPS MONITORING	
			ECS REDUNDANT COMPONENT CHECK	ECS REDUNDANT COMPONENT CHECK	EPS MONITORING	
	30		DOCKING PROBE CHECK	TRANSFER TO LOWER EQUIPMENT BAY (LEB)	BATTERY CHARGER CHECK	
					SINGLE & DUAL INVERTER OPERATION CHECK	
					PYRO BATTERY CHECK	
	40		PIPA BIAS CHECK	PREPARE LEB NAVIGATION STATION	SPS LINE HEATERS CHECK & MANUAL CRYO HEATERS AND FANS TEST	
			ENTRY MONITORING SYSTEM CHECK			
1st PACIFIC	50	CARNARVON	COMMUNICATIONS TEST & TIME HACK	PERFORM IMU FINE ALIGNMENT		
	60		C & W SYSTEM VERIFICATION		C & W SYSTEM VERIFICATION	
			NO PLANNED ACTIVITY		NO PLANNED ACTIVITY	
	70		SM RCS THRUSTER FIRING TEST	SECURE LEB NAVIGATION STATION		
			SCS ALIGNMENT	CONDITION LAMP TEST WATER GUN TEST URINATION		
	80	HAWAII				
	90	USA	PARTICIPATE IN ECS POST CHECK GUIDANCE AND NAVIGATION SYSTEM ΔV PREPARATIONS INCLUDING STATE VECTOR & THRUSTING PARAMETER UPDATES	ECS POST CHECK	ECS POST CHECK	
2nd ATLANTIC	100					
	110			ASSIST IN G & N SYSTEM PREPARATIONS AND TRANSFER TO COUCH	NO PLANNED ACTIVITY	
	120	ASCENSION				
	130				FUEL CELL PURGE	
	140		FINAL TLI PREPARATIONS (THRUSTING PROGRAM CHECK)	FINAL TLI PREPARATIONS (ASSIST IN THRUSTING PROGRAM CHECK)	FINAL TLI PREPARATIONS	
2nd PACIFIC	150	CARNARVON	TLI	TLI	TLI	

*BASED ON A 90° FLIGHT AZIMUTH FOR A COMPLETE LUNAR MONTH

TABLE II

DEFINITIONS

CM	Command Module
CMC	Command Module Computer
CRYO	Cryogenic
C&W	Caution and Warning
ECS	Environmental Control System
EMS	Entry Monitoring System
EPS	Electrical Power System
fps	Feet Per Second
G&N	Guidance and Navigation
IMU	Inertial Measurement Unit
IU	Instrument Unit
LEB	Lower Equipment Bay
MCC	Midcourse Correction
MSFN	Manned Space Flight Network
PIPA	Pulsed Integrating Pendulous Accelerometer
PYRO	Pyrotechnic
RCS	Reaction Control System
SCS	Stabilization and Control System
SM	Service Module
SPS	Service Propulsion System
S-IVB	Third Stage of Saturn V Launch Vehicle
TLI	Translunar Injection
ΔV	Incremental Velocity

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Subject: Constraints on the Apollo Earth Orbital Timeline Case 310

FROM: R. E. Driscoll

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